# Air Conditioning Effects in MOBILE6

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**U.S. EPA Office of Mobile Sources**

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# Outline

- MOBILE6 Air Conditioning Corrections
  - Emissions
  - Activity
  - Market Penetration

# Air Conditioning - Testing

- 38 vehicles tested at EPA, ATL
- “EPA Simulation”: 95 deg F, driver window down
  - Correlation vehicle tested in environmental chamber indicates adequate vehicle loading
- Represents emission levels under full A/C system loading (“Full-Usage”)

# Air Conditioning - Emissions

- Initial Proposal: Multiplicative adjustments dependent on speed for all pollutants
- Why proposal was discarded:
  - Not applicable to older or future model years
  - Take into account base emissions

# Emissions Continued: ANOVA Analysis

- Looked at all three pollutants separately
- ANOVA
  - Dependent: A/C effect (A/C On-A/C Off)
  - Independent: $A/C_{base}$ , Speed, Vehicle Class, Facility
    - took high and normal emitters into consideration
- Looked at two different fits:
  - linear space
  - log space

# NOx Emissions

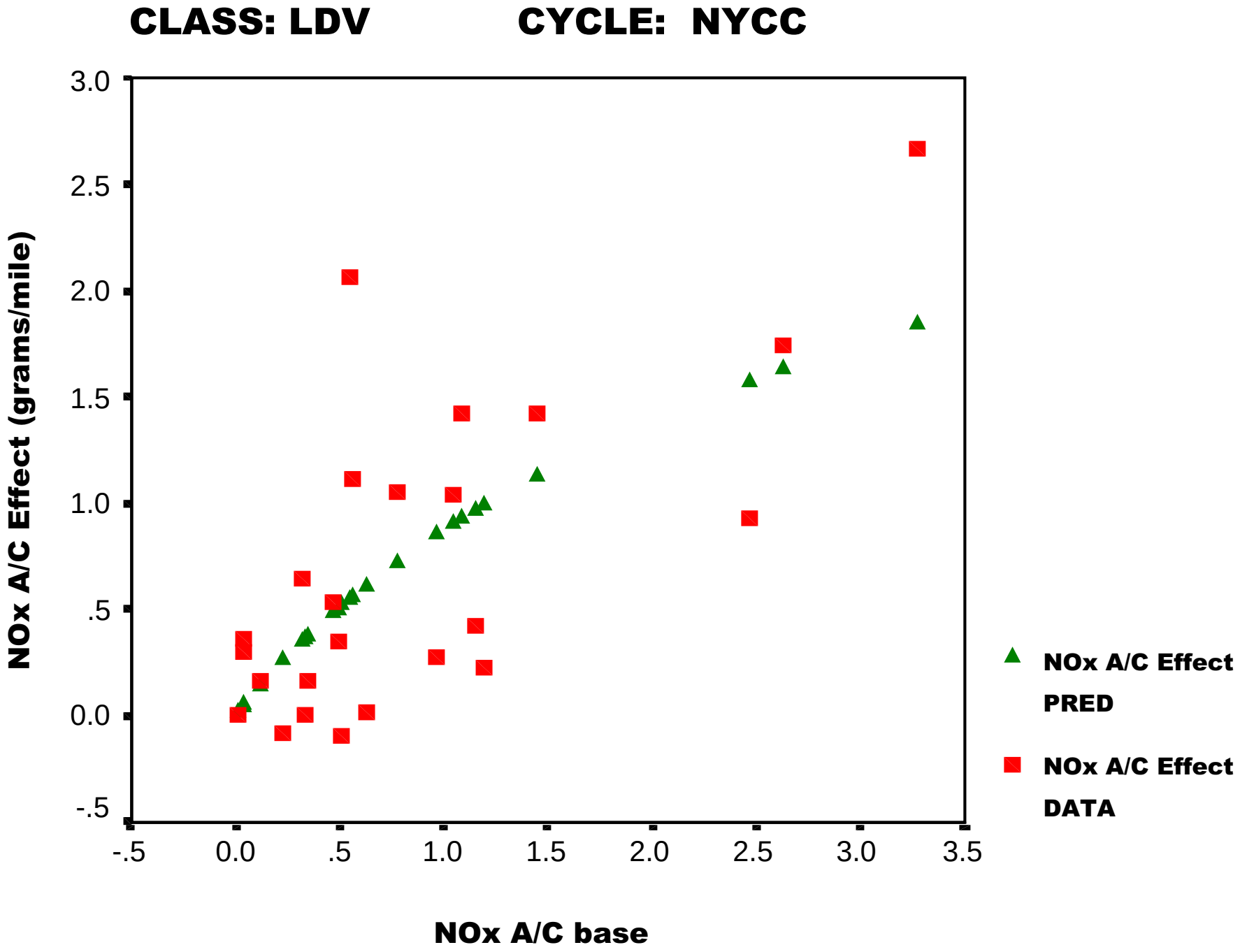
- ANOVA
- Conclusions
  - Separate LDV vs. LDT
  - Separate Ramp

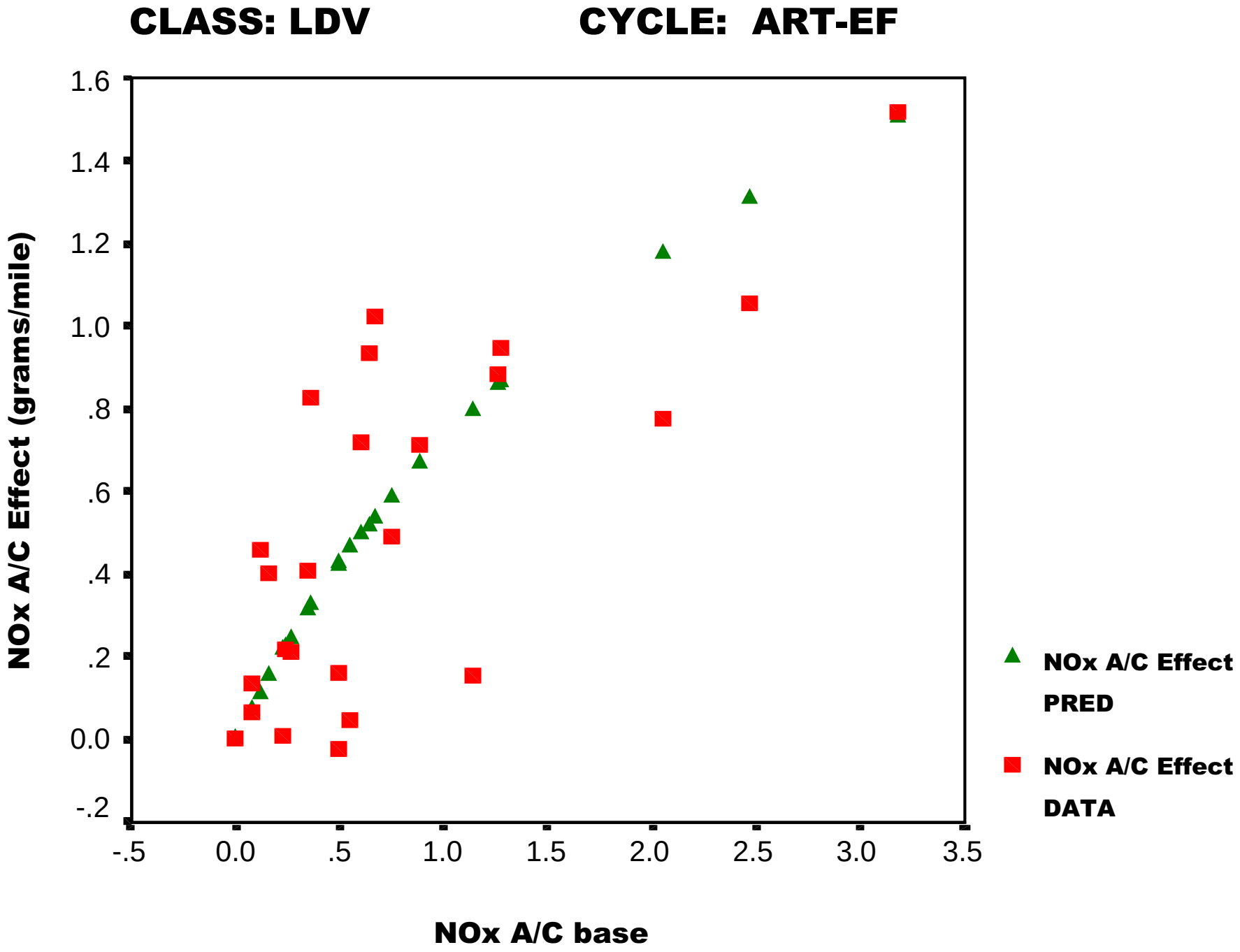
# NOx Emissions Continued: Light-Duty Vehicles and Trucks

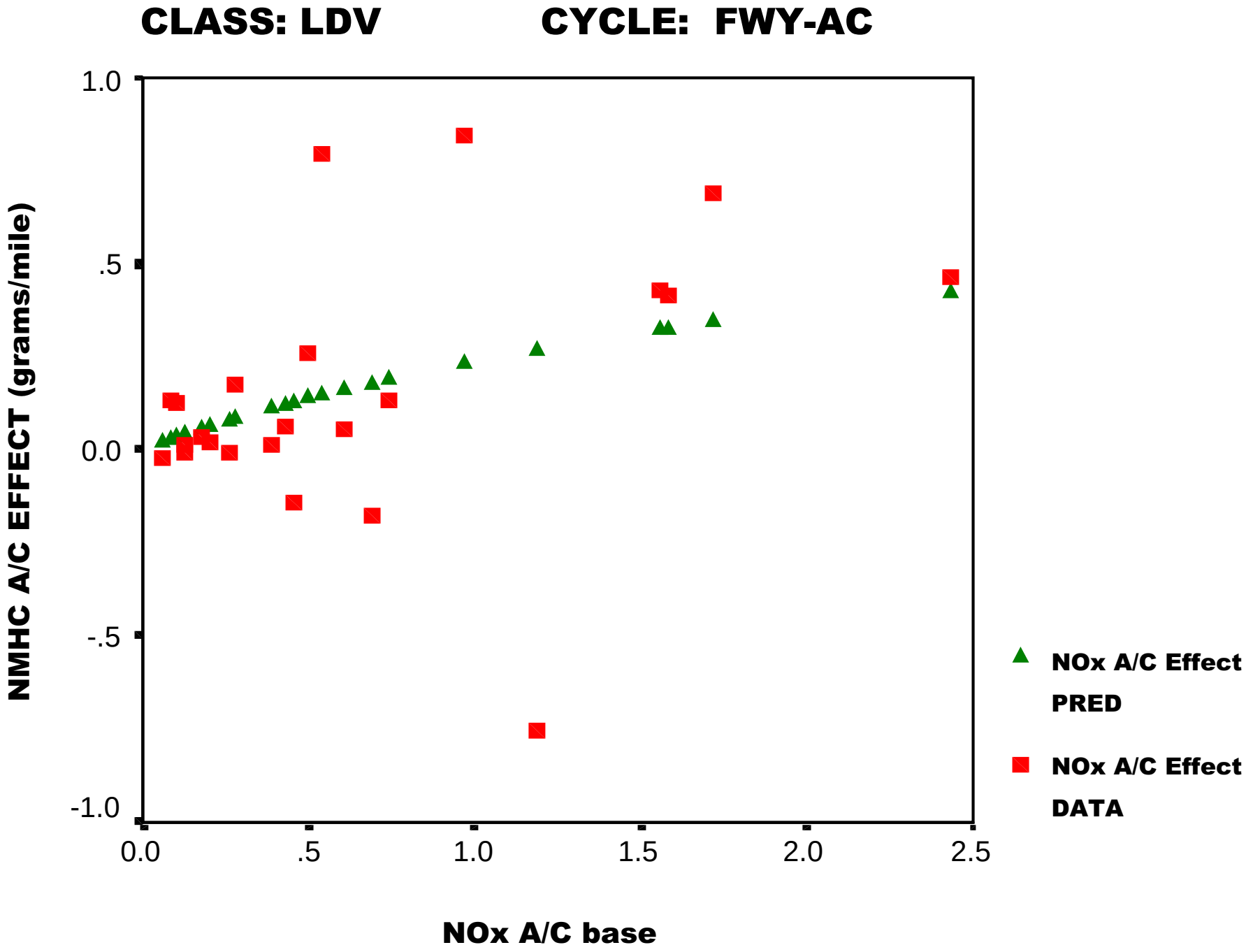
- ANOVA over all facilities except Ramp
  - Dependent: NOx A/C effect
  - Independents: Log (NOx A/$C_{base}$ +1), Log (Speed)
- Conclusion:
  - Interactive effect with speed and base emissions

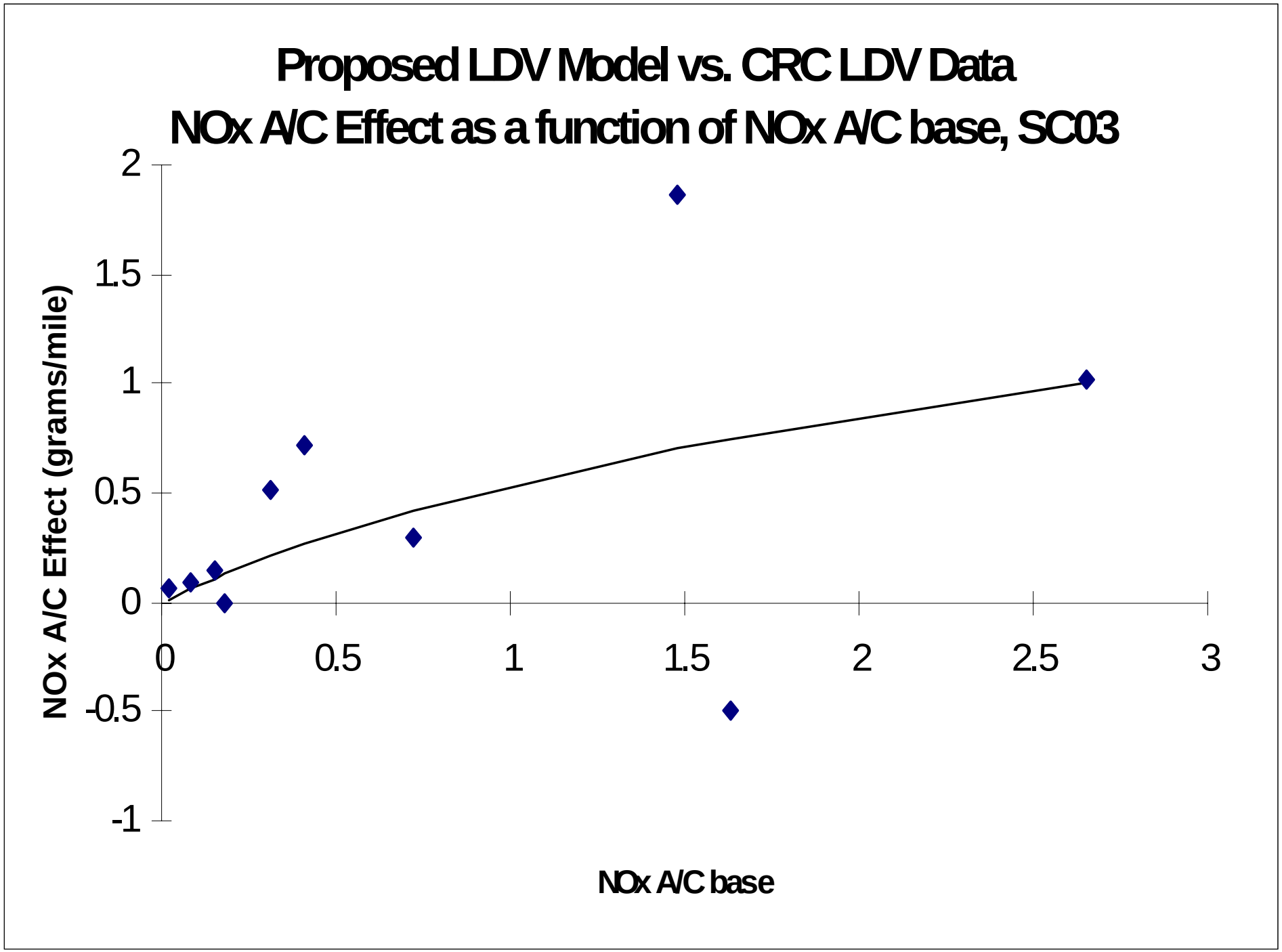
# NOx Emissions Continued: Final Equations:

- Light-duty Vehicles
  - **NOx A/C Effect=4.867 Log(NOx A/$C_{base}$ +1)-2.296 (Log(Speed)*Log(NOx A/$C_{base}$ + 1))**
- Light-duty Trucks
  - **NOx A/C Effect= 1.93 Log(NOx A/$C_{base}$+1)-0.769(Log(Speed)*Log(NOx A/$C_{base}$ + 1))**


CLASS: LDV
CYCLE: NYCC
NOx A/C Effect (grams/mile)
3.0
2.5
2.0
1.5
1.0
.5
0.0
-.5
-.5
0.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
NOx A/C base
NOx A/C Effect PRED
NOx A/C Effect DATA


CLASS: LDV
CYCLE: ART-EF
NOx A/C Effect (grams/mile)
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0.0
-.2
-.5
0.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
NOx A/C base
NOx A/C Effect PRED
NOx A/C Effect DATA


CLASS: LDV
CYCLE: FWY-AC
NMHC A/C EFFECT (grams/mile)
1.0
.5
0.0
-.5
-1.0
0.0
.5
1.0
1.5
2.0
2.5
NOx A/C base
NOx A/C Effect PRED
NOx A/C Effect DATA


Proposed LDV Model vs. CRC LDV Data
NOx A/C Effect as a function of NOx A/C base, SC03
NOx A/C Effect (grams/mile)
2
1.5
1
0.5
0
-0.5
-1
0
0.5
1
1.5
2
2.5
3
NOx A/C base

# CO Emissions

- ANOVA Analyses
- Conclusions:
  - Separate Local Cycles (Local & NYCC)
  - Separate LDV vs LDT
  - Separate by emission classification

# CO Emissions Continued: LDV and LDT Normal Emitters

- ANOVA
  - Dependent:  CO A/C Effect
  - Independent:  CO $A/C_{base}$ , Speed
- Conclusions:
  - LDV:  CO $A/C_{base}$  and Speed are significant
  - LDT:  Speed is significant

# CO Emissions Continued: Normal Emitter Final Equations

- Light-duty Vehicles:
  - CO A/C Effect = (.815*(CO $A/C_{base}$) +.05272*(Speed))
- Light-duty Trucks:
  - CO A/C Effect = .104*(Speed)

# NMHC Emissions

- ANOVA
- Conclusion:
  - vehicle class not significant
  - NMHC $A/C_{base}$ is significant
  - Separate by emission classification

# NMHC Emissions Continued: Normal Emitters

- ANOVA
  - Dependent:  NMHC A/C Effect
  - Independent: $NMHC_{base}$ , Speed, Facility, Class
- Conclusion:
  - Separate Local Cycle
  - Speed is significant
- Final Equation for all vehicle classes:
  - NMHC A/C Effect = .001162(Speed)

# Continuing Emissions Analysis

- NOx Emissions
  - Ramp Cycle
- CO Emissions
  - High Emitters (for non-local cycles)
  - Local Cycle
- NMHC Emissions
  - Local Cycle for Normal Emitters
  - High Emitters (for all cycles)

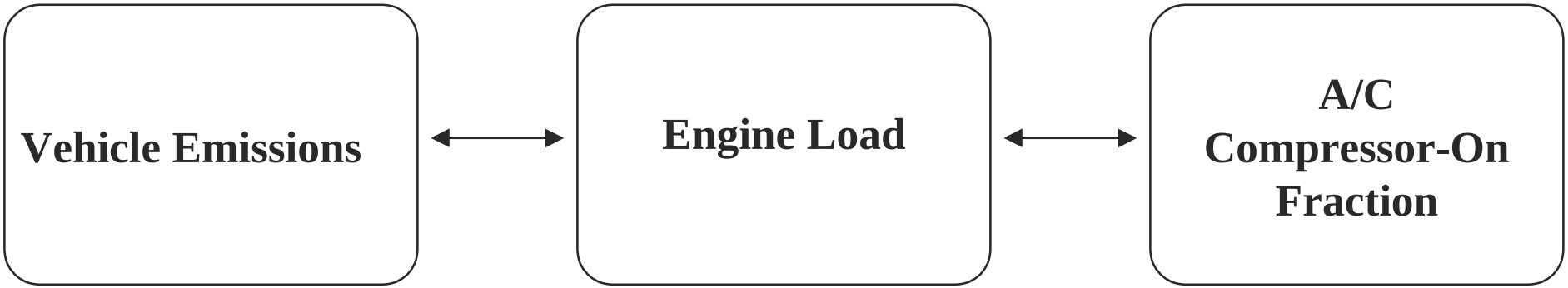
# Air Conditioning Effects in MOBILE6

- Light-duty Vehicle Effects
  - LDV & LDT1
- Light-duty Truck Effects
  - LDT2, LDT3, LDT4
- Heavy-duty Gasoline Trucks
  - still under consideration
  - likely based on light-duty truck data

# Air Conditioning Activity

- Account for in-use conditions
- Demand factor- Scales back full usage emissions based on temperature and humidity
- Demand factor = Fraction of time A/C compressor is engaged at given temperature and humidity (full usage = compressor engaged 100% of time)

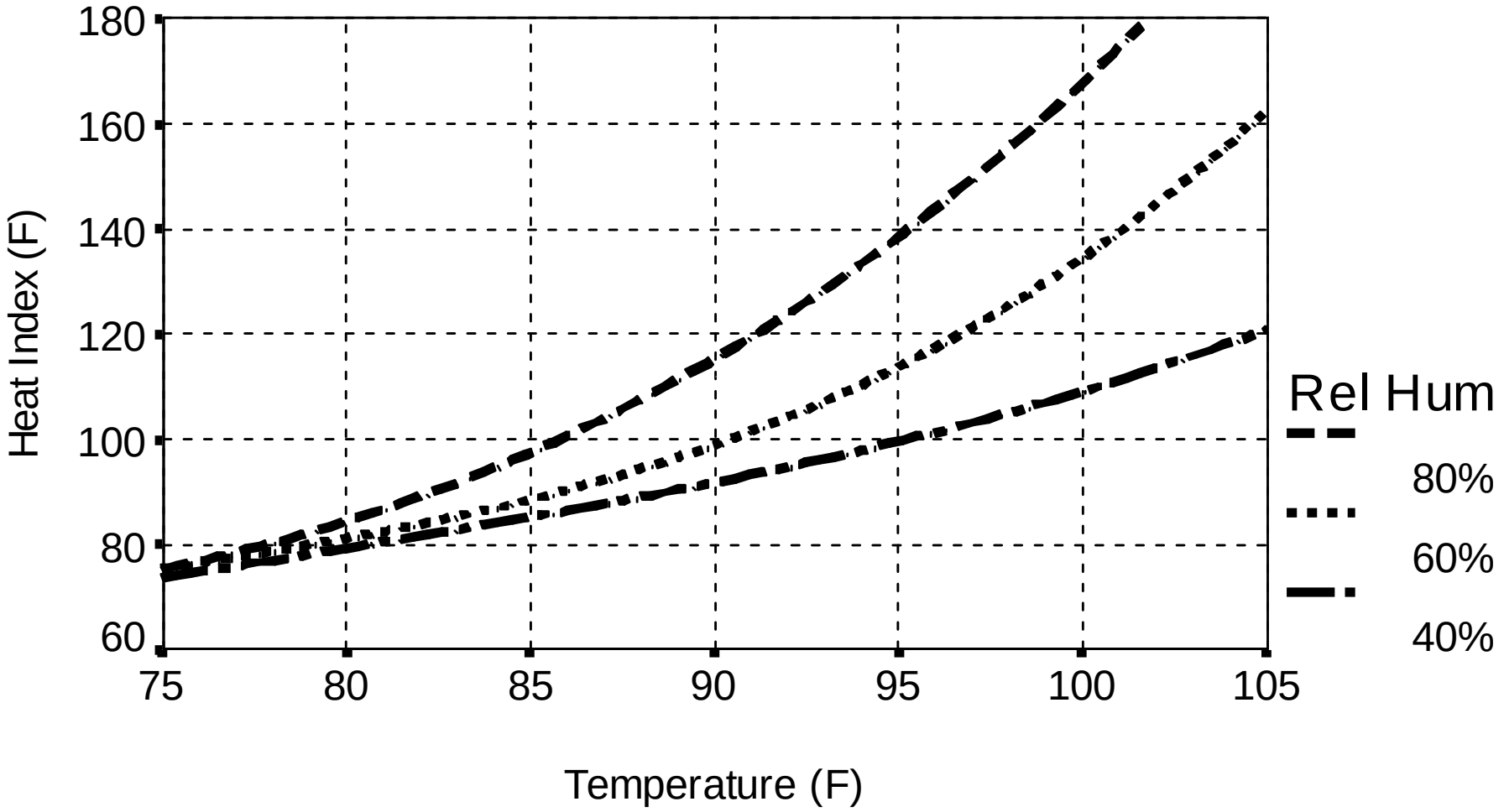
# A/C Compressor-On Fraction and Vehicle Emissions Relationship



# Air Conditioning  Activity: Heat Index

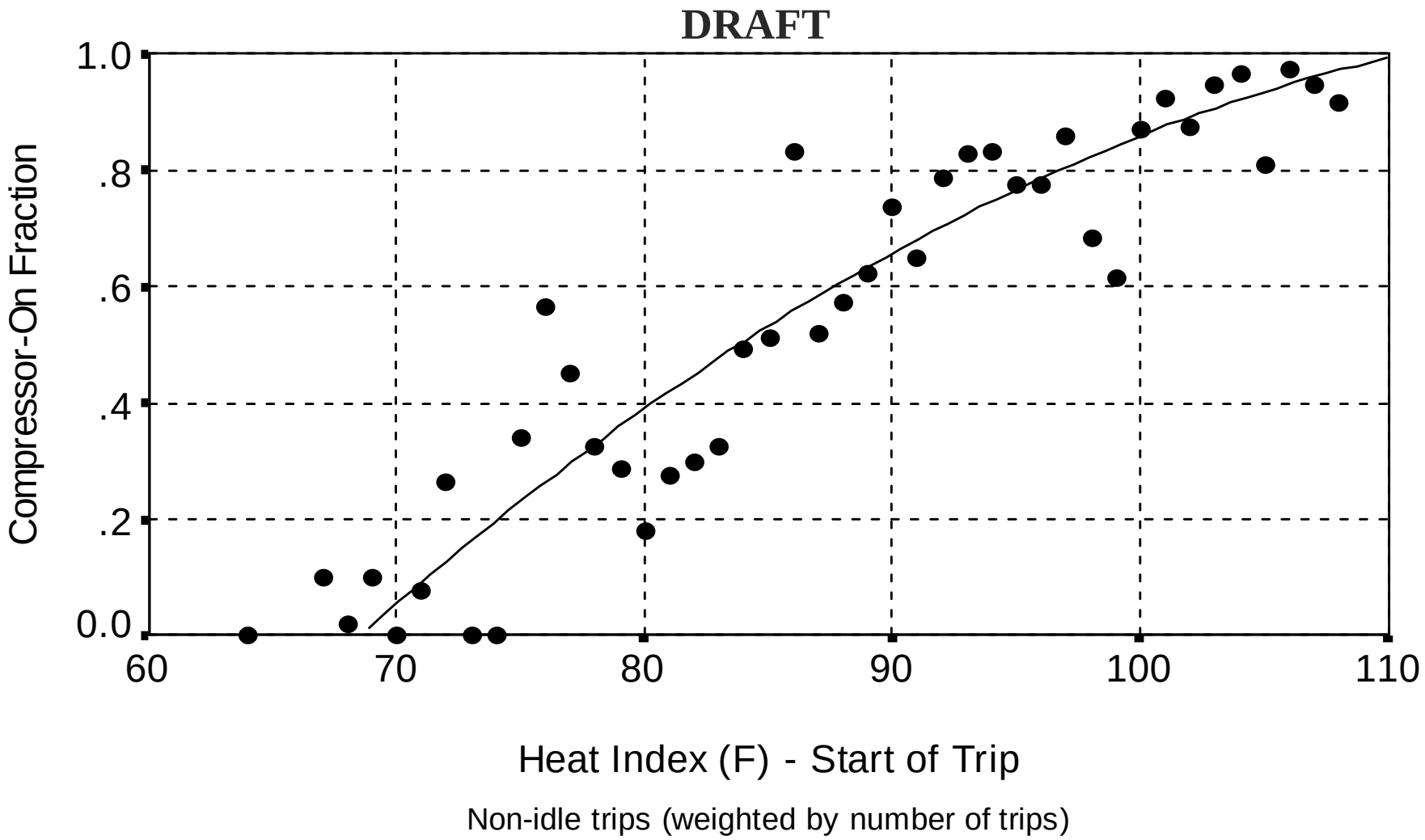
- Heat Index estimates driver discomfort by combining temperature and humidity
- Heat index vs. compressor-on relationships developed from Phoenix A/C survey data
  - 1994 SFTP project
  - 20 vehicles, late summer

# Heat Index




Note: Heat Index values based on shady conditions

# Compressor-On vs. Heat Index



# A/C Activity Continued: Solar Load

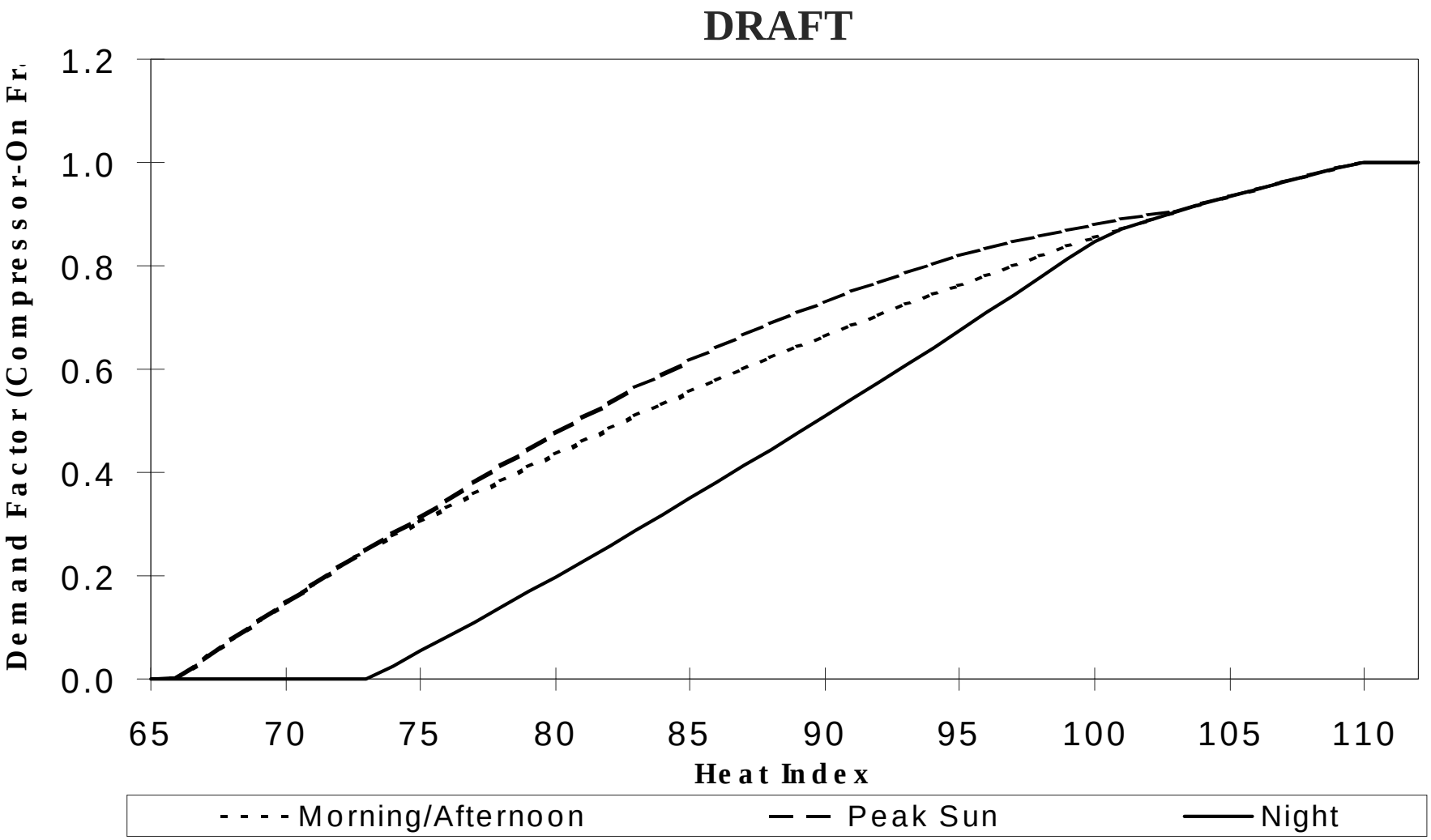
Solar Load:

- Fraction of time A/C compressor is engaged varies by time of day
  - Three different curves:
    - Morning/Afternoon (sunrise-10am & 4pm-sunset)
    - Peak Sun (10am-4pm)
    - Nighttime (sunset-sunrise)

# A/C Activity Continued: Cloud Cover

- MOBILE default: 0% cloud cover = daytime curve
- Cloud cover handled by assuming "night" curve = 100% cloud cover
- Intermediate conditions:  interpolate in-between 0% and 100% levels

# A/C Demand Factor Curves



# Air Conditioning Activity - Market Penetration

Three Elements:

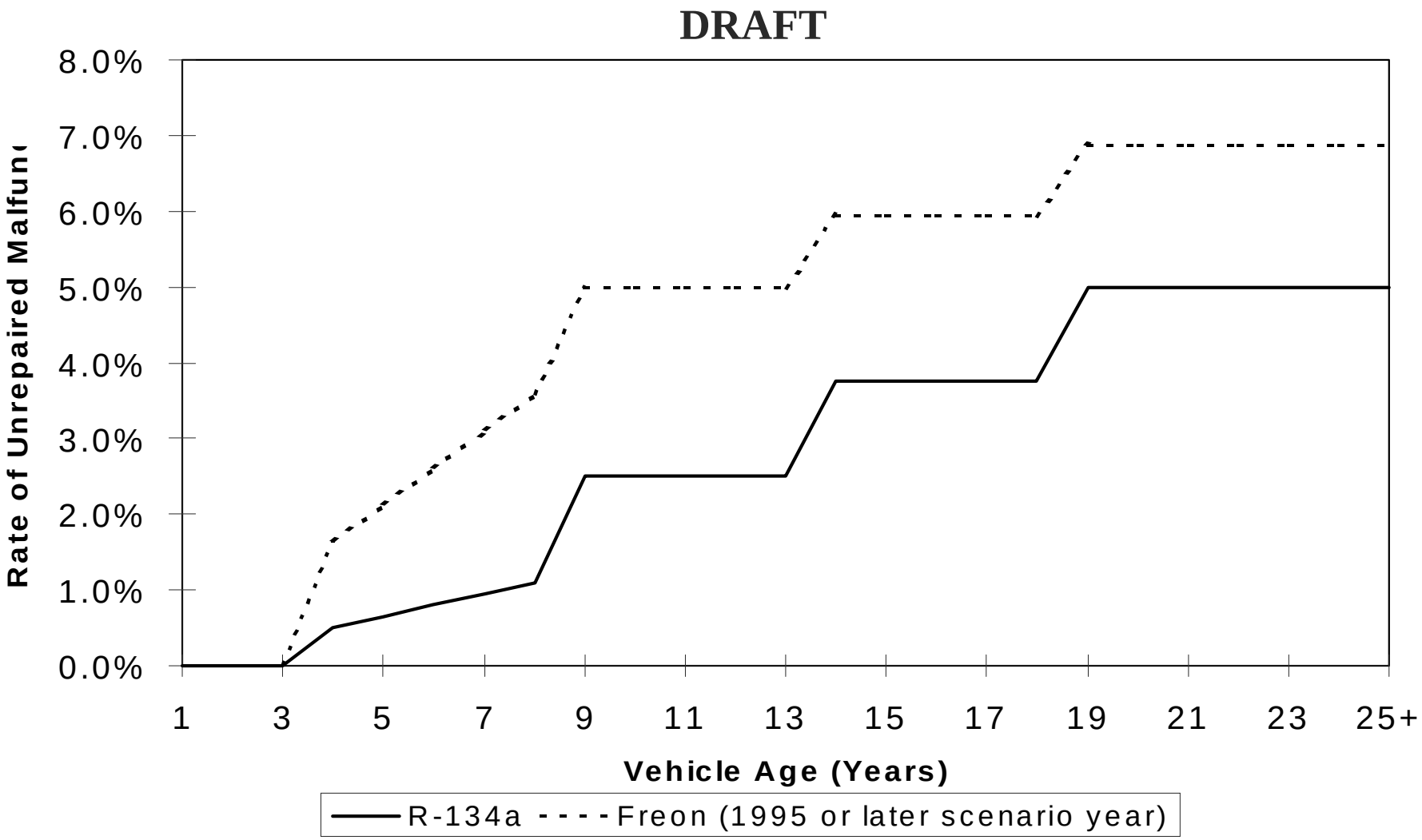
① Fraction of A/C-equipped vehicles

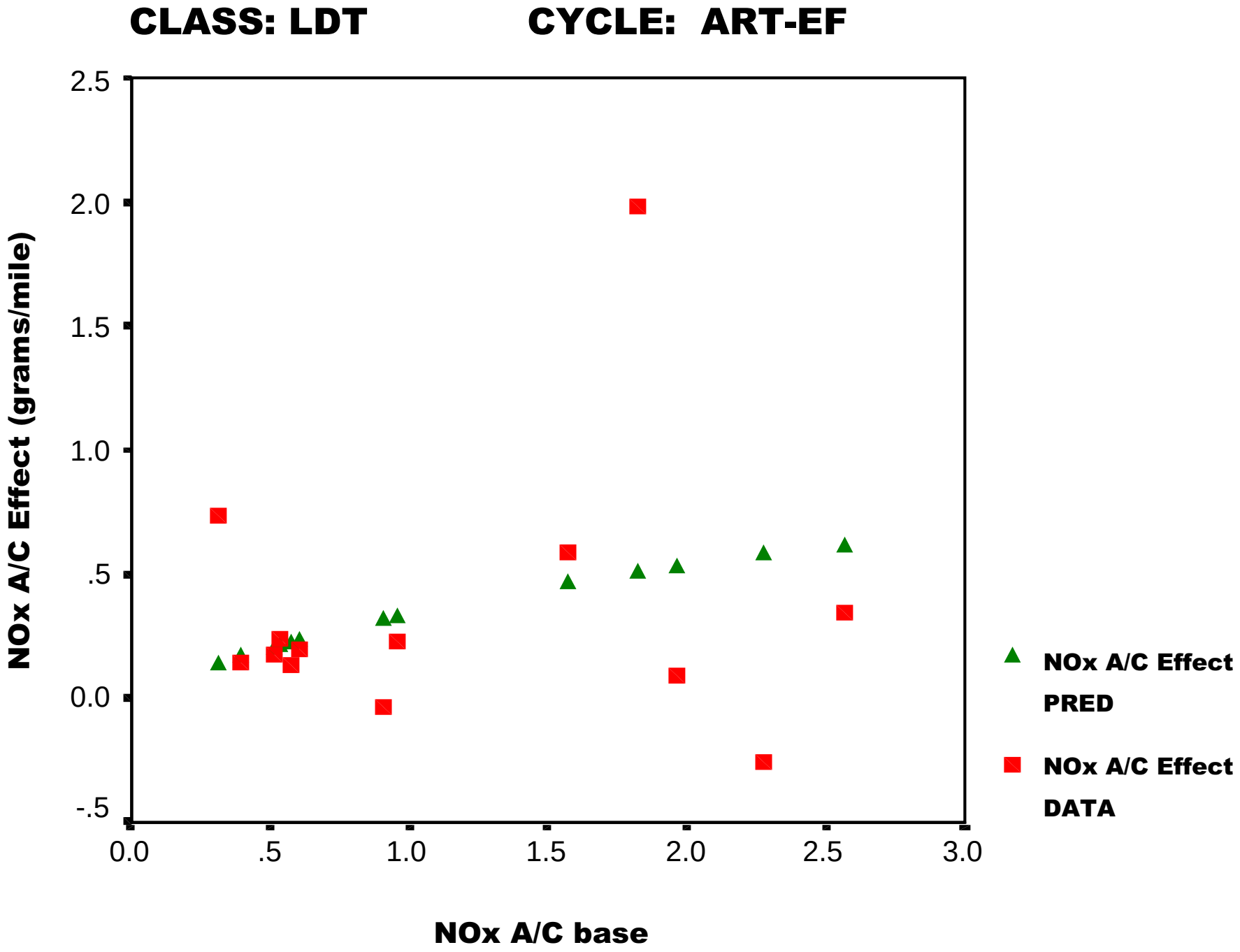
② Fraction of  (1) with A/C malfunctions

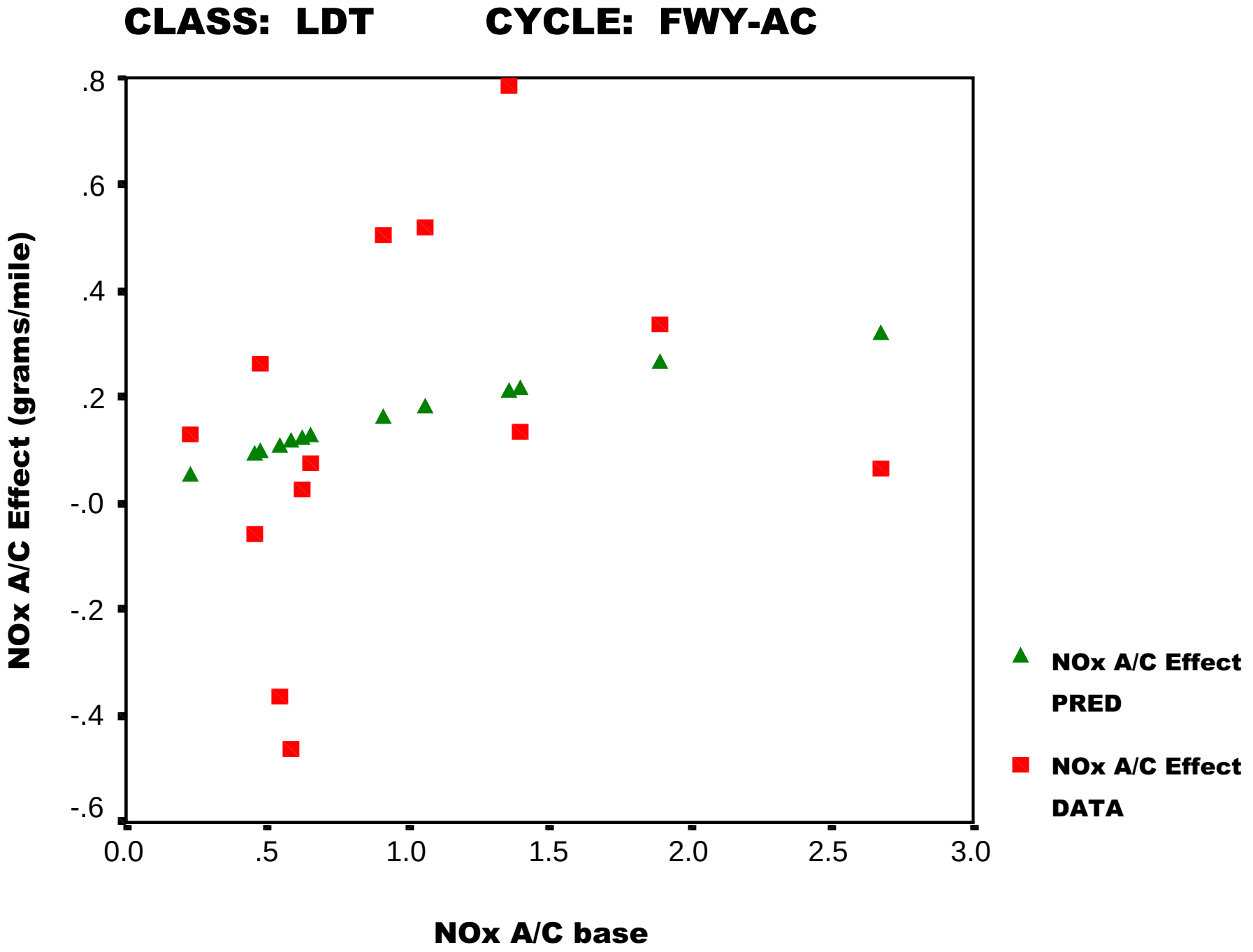
③ Fraction of (2) not repaired

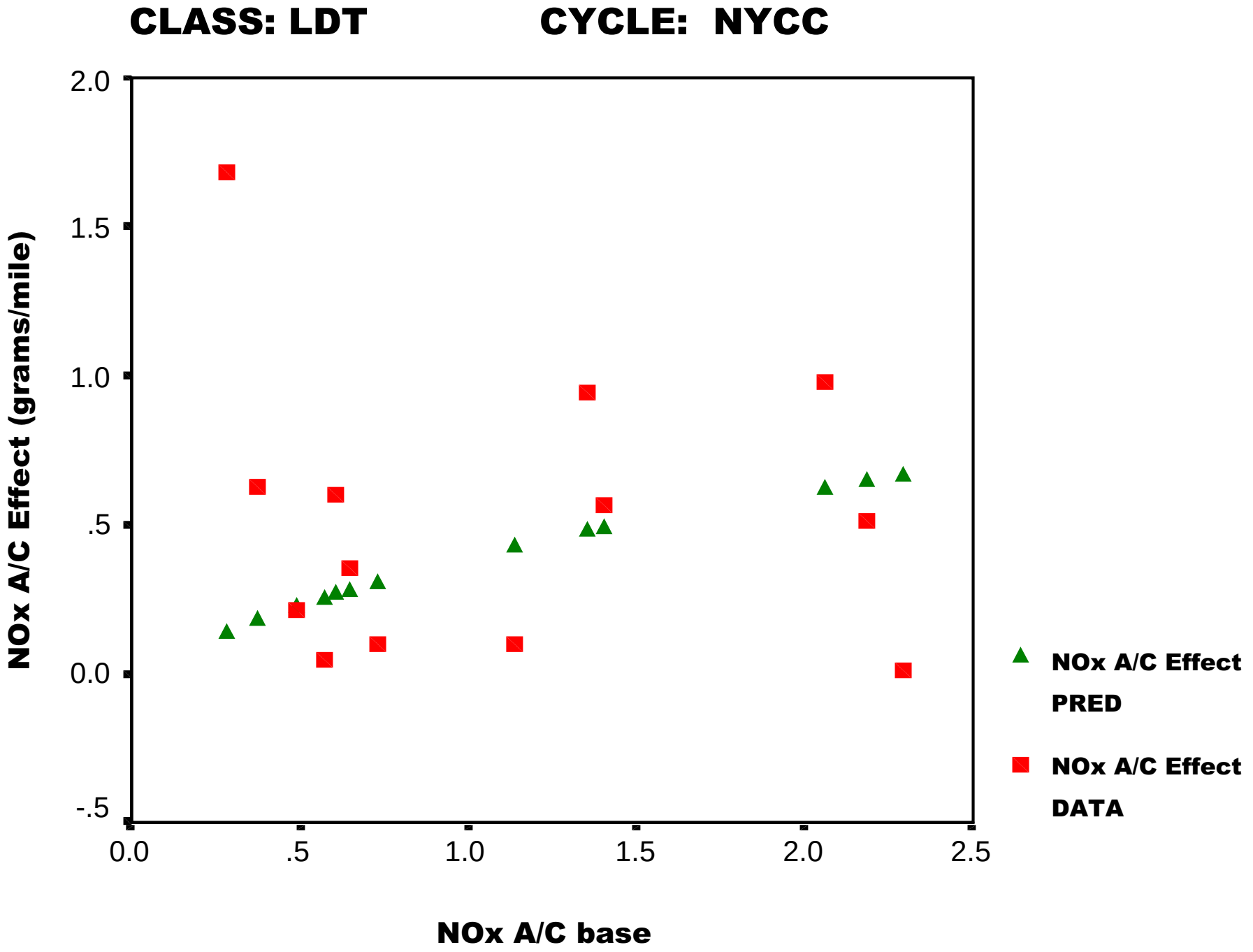
- Warranty
- Vehicle Age
- Freon vs. R-134a

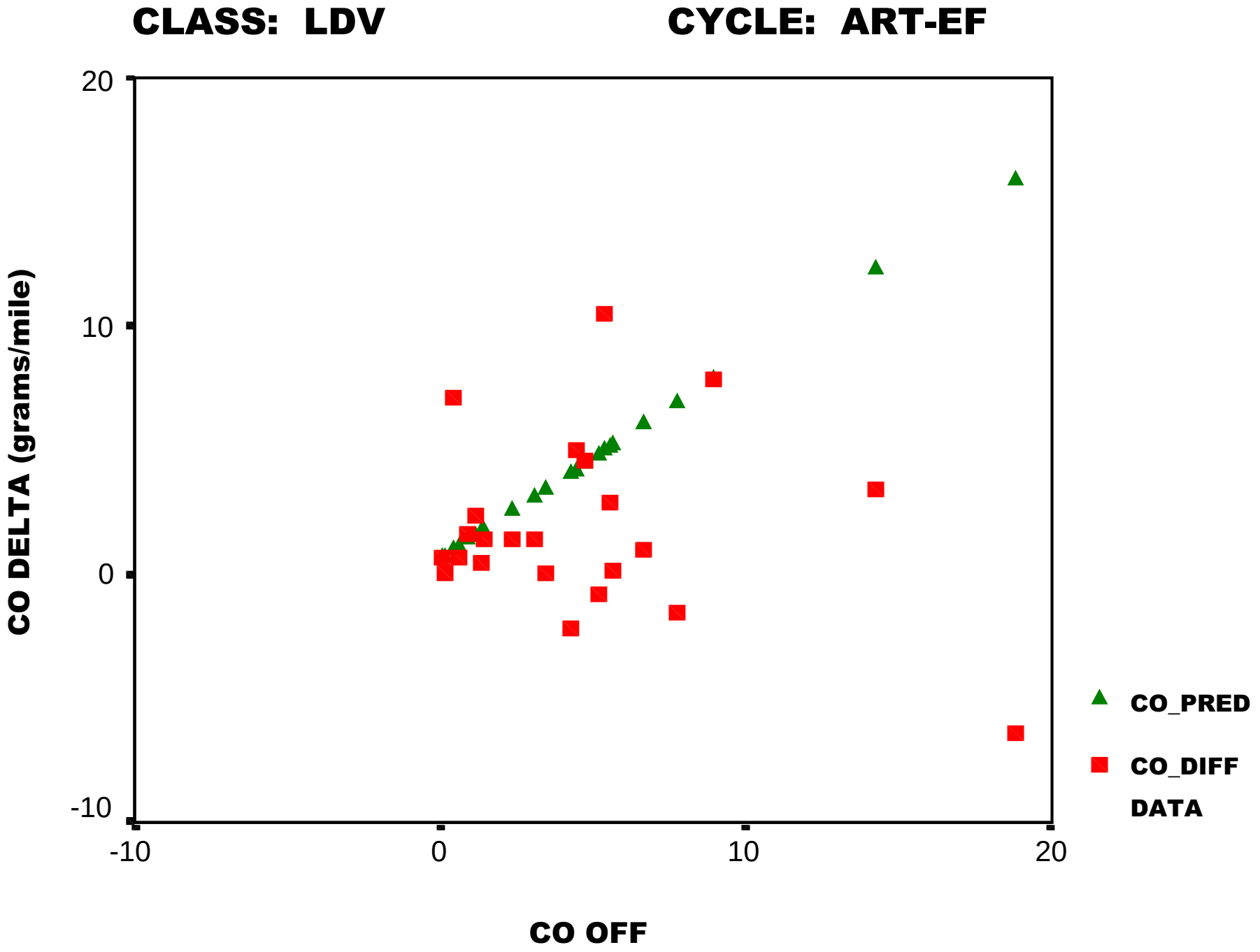
# Unrepaired A/C Malfunctions

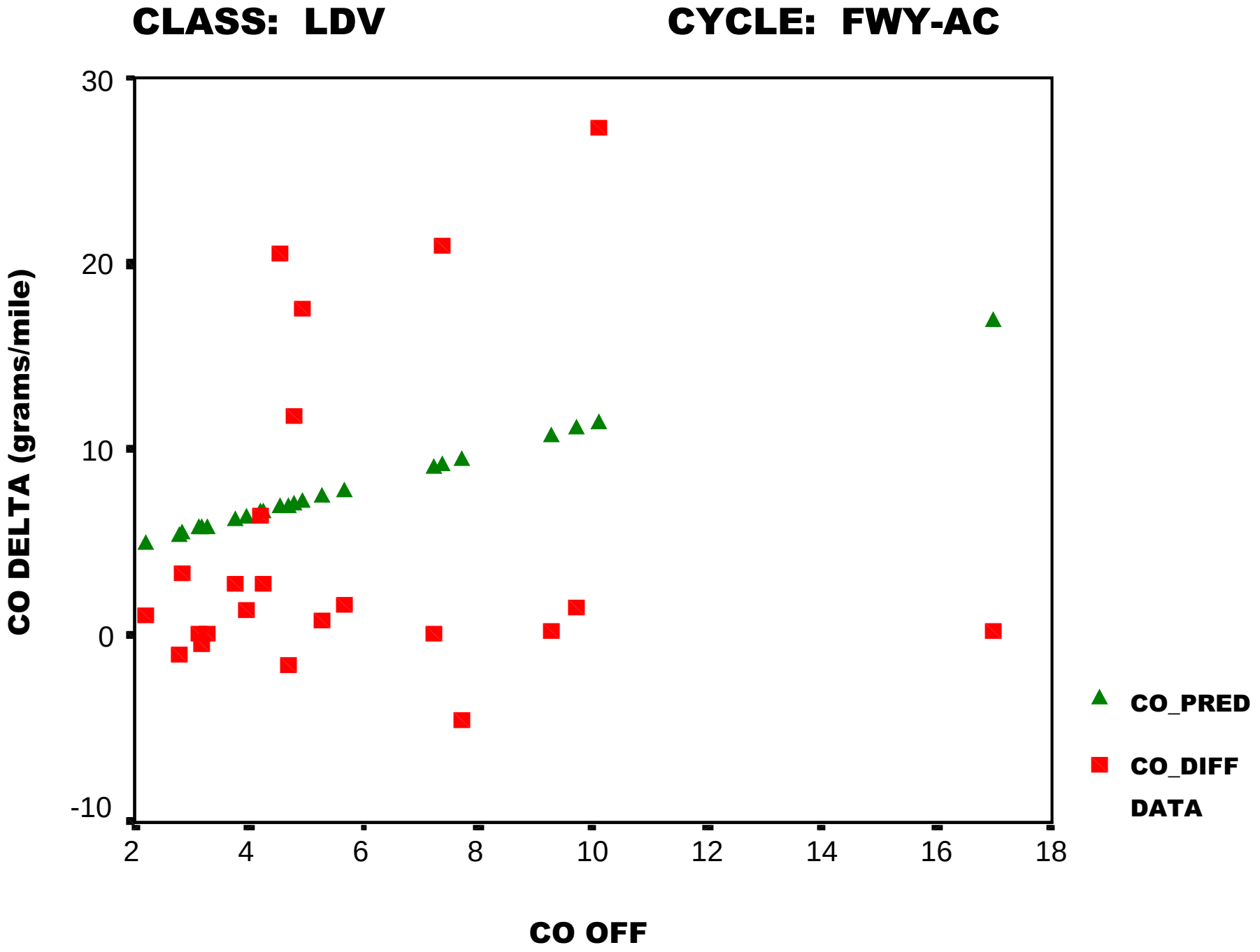


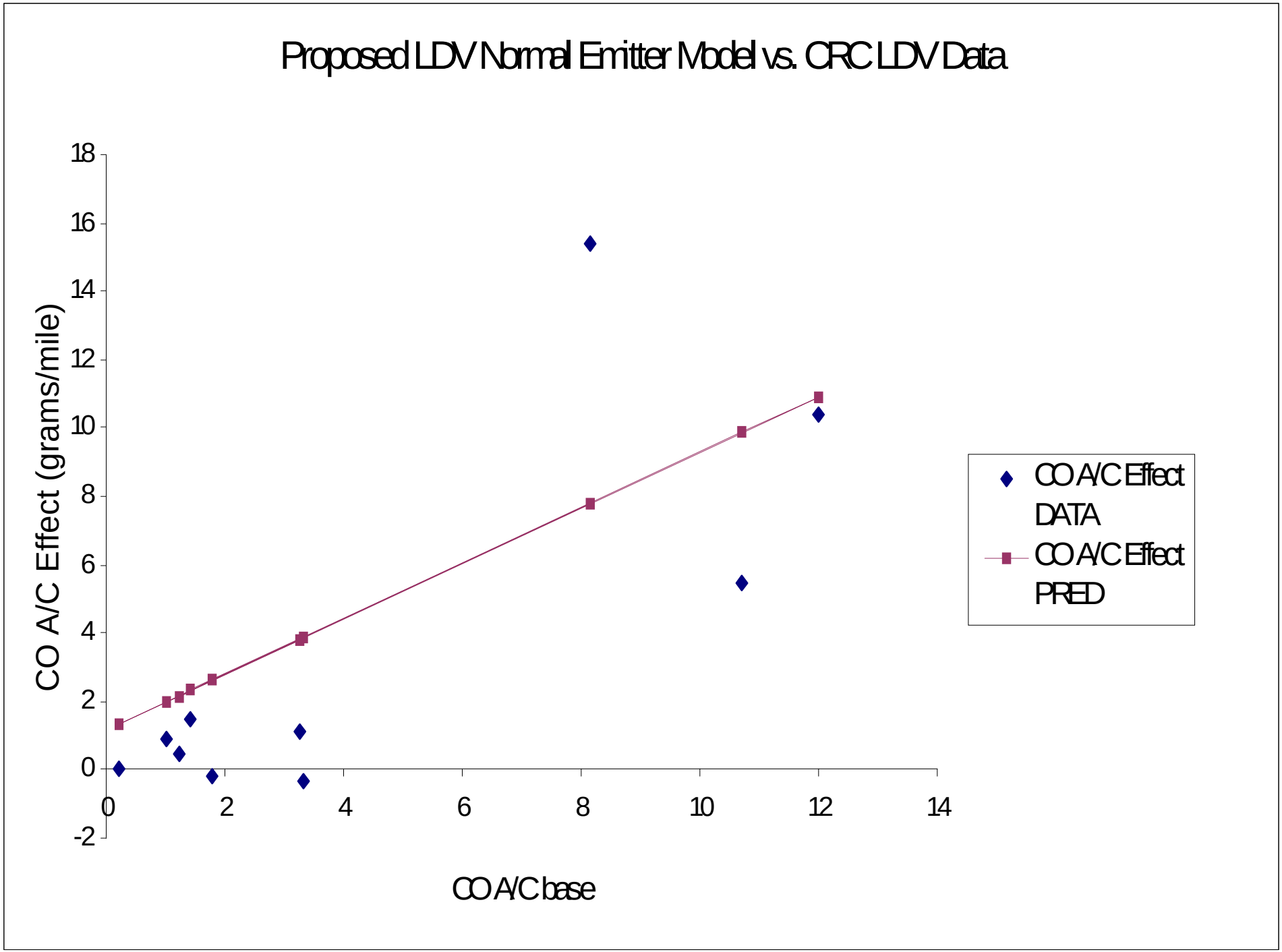

CLASS: LDT
CYCLE: ART-EF
NOx A/C Effect (grams/mile)
2.5
2.0
1.5
1.0
.5
0.0
-.5
0.0
.5
1.0
1.5
2.0
2.5
3.0
NOx A/C base
NOx A/C Effect PRED
NOx A/C Effect DATA

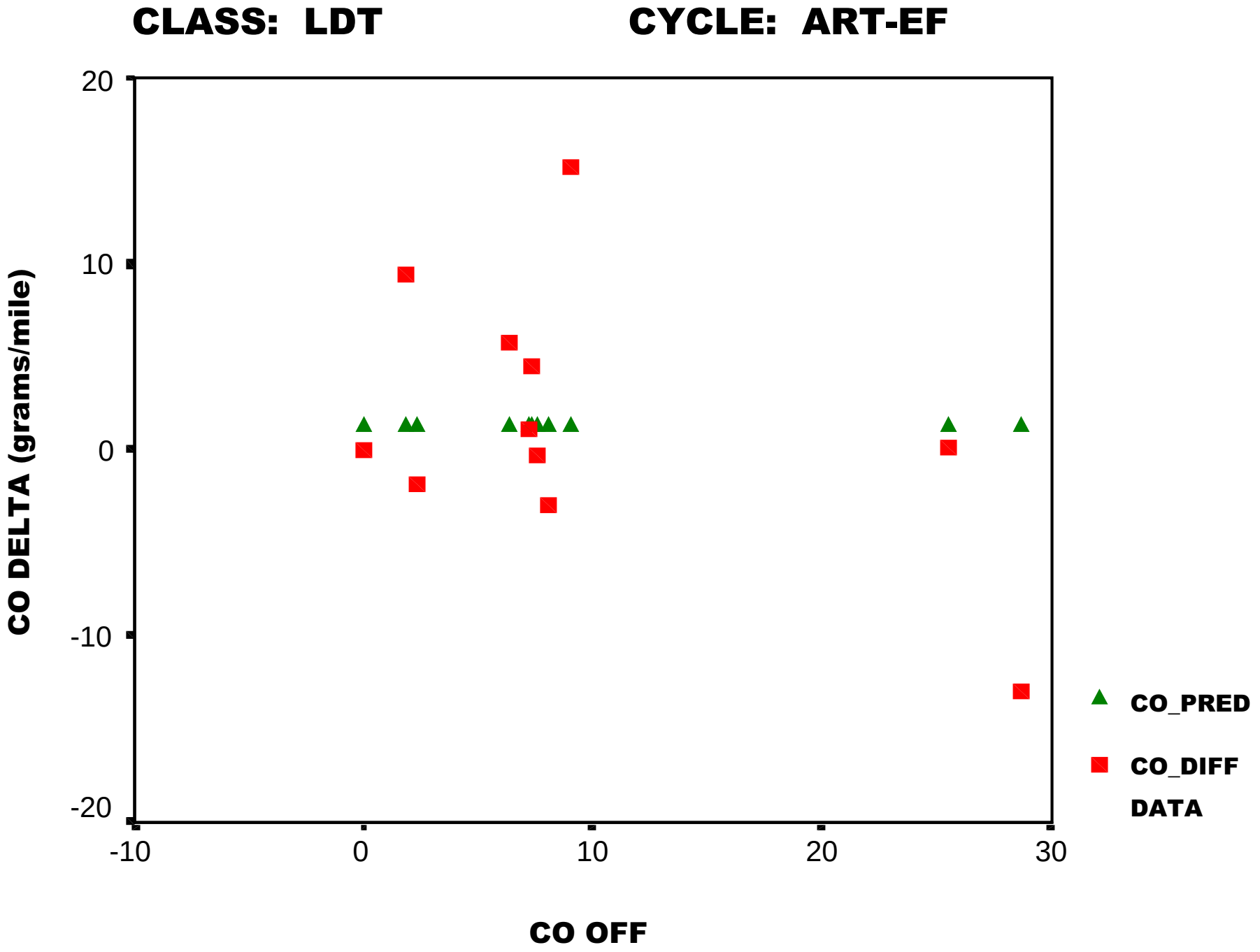

CLASS: LDT
CYCLE: FWY-AC
NOx A/C Effect (grams/mile)
.8
.6
.4
.2
-.0
-.2
-.4
-.6
0.0
.5
1.0
1.5
2.0
2.5
3.0
NOx A/C base
NOx A/C Effect PRED
NOx A/C Effect DATA

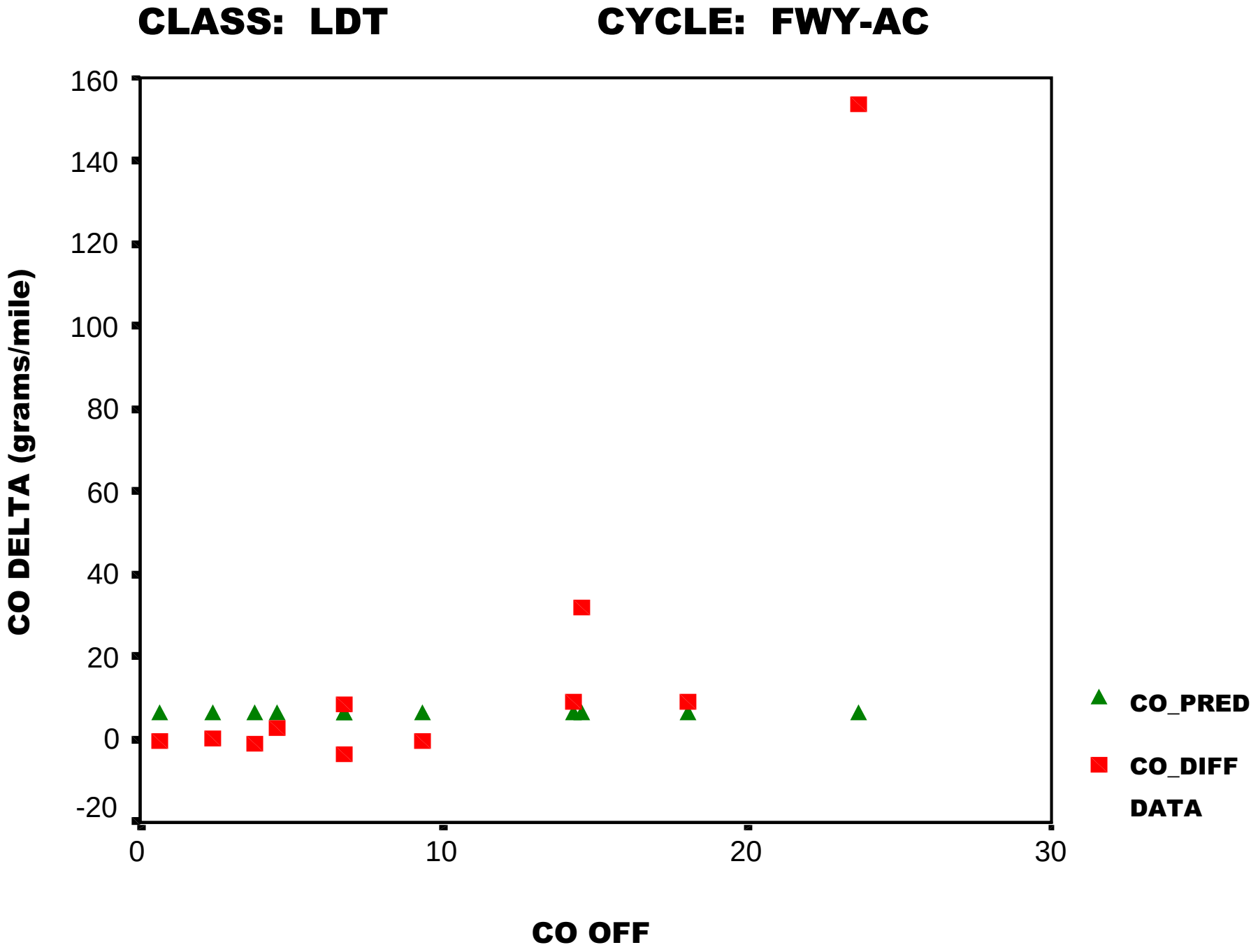

CLASS: LDT
CYCLE: NYCC
NOx A/C Effect (grams/mile)
2.0
1.5
1.0
.5
0.0
-.5
0.0
.5
1.0
1.5
2.0
2.5
NOx A/C base
NOx A/C Effect PRED
NOx A/C Effect DATA

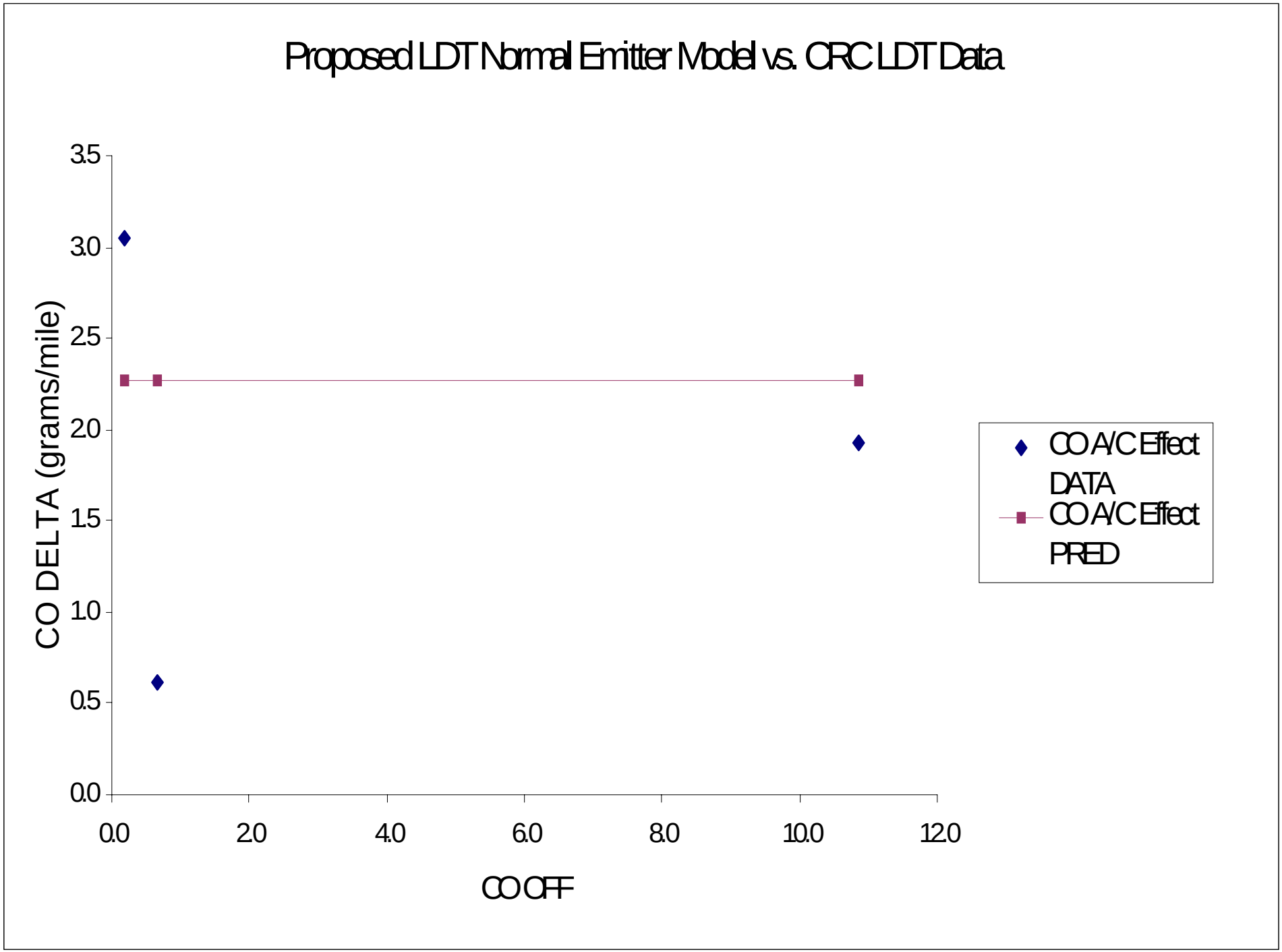

CLASS: LDV
CYCLE: ART-EF
CO DELTA (grams/mile)
20
10
0
-10
-10
0
10
20
CO OFF
CO_PRED
CO_DIFF
DATA

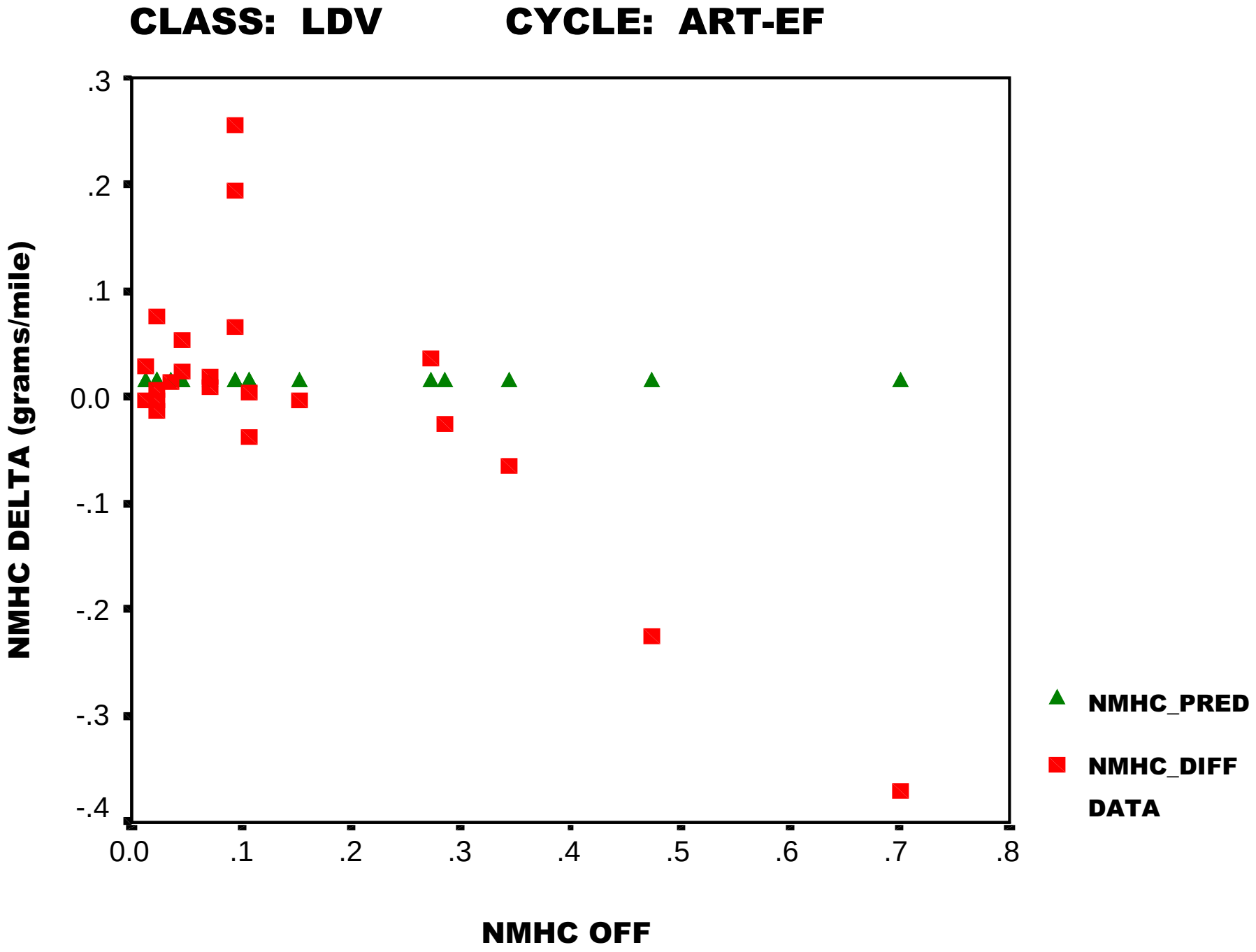

CLASS: LDV
CYCLE: FWY-AC
CO DELTA (grams/mile)
30
20
10
0
-10
2
4
6
8
10
12
14
16
18
CO OFF
CO_PRED
CO_DIFF
DATA

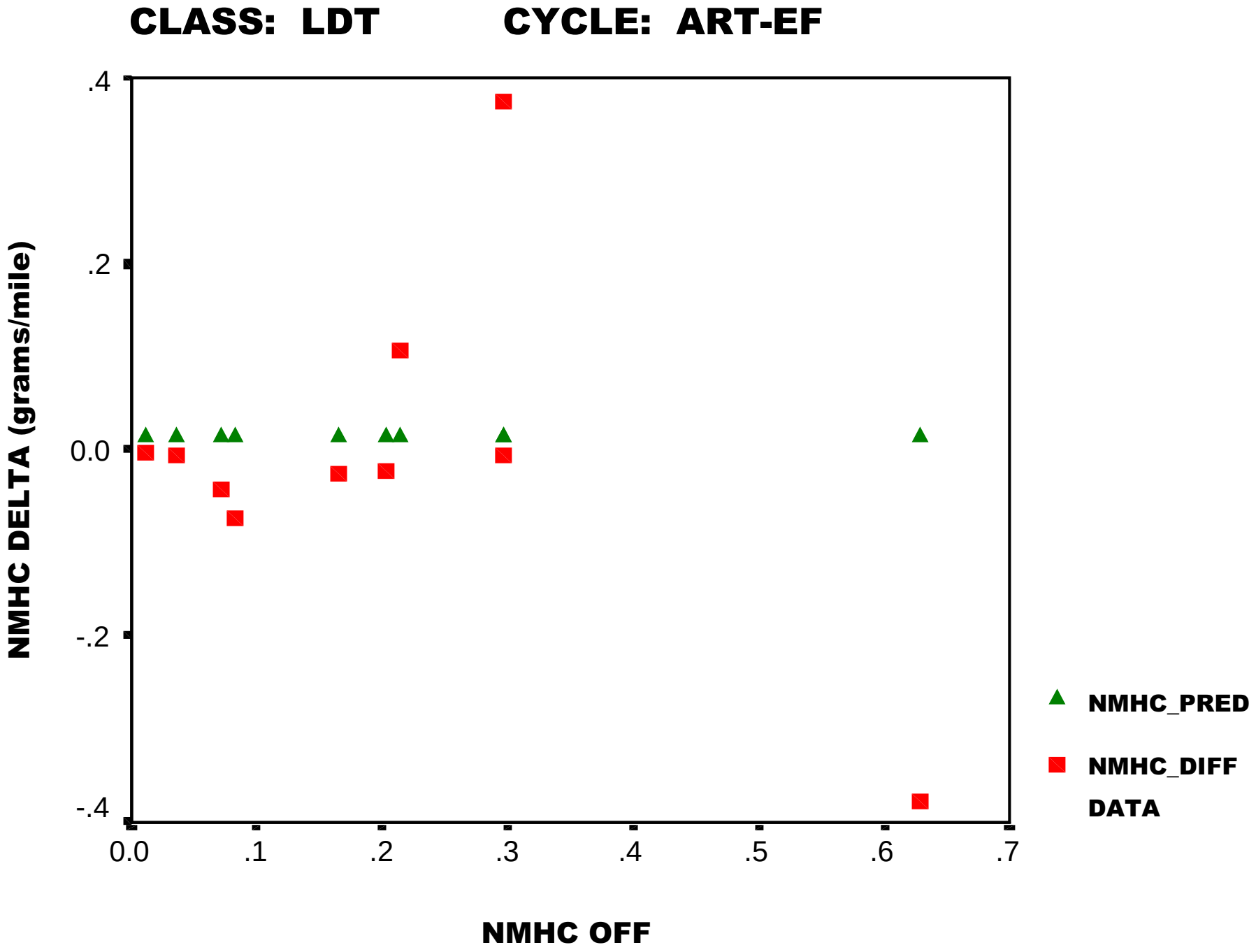

Proposed LDV Normal Emitter Model vs. CRC LDV Data
CO A/C Effect (grams/mile)
18
16
14
12
10
8
6
4
2
0
-2
0
2
4
6
8
10
12
14
CO A/C base
CO A/C Effect DATA
CO A/C Effect PRED

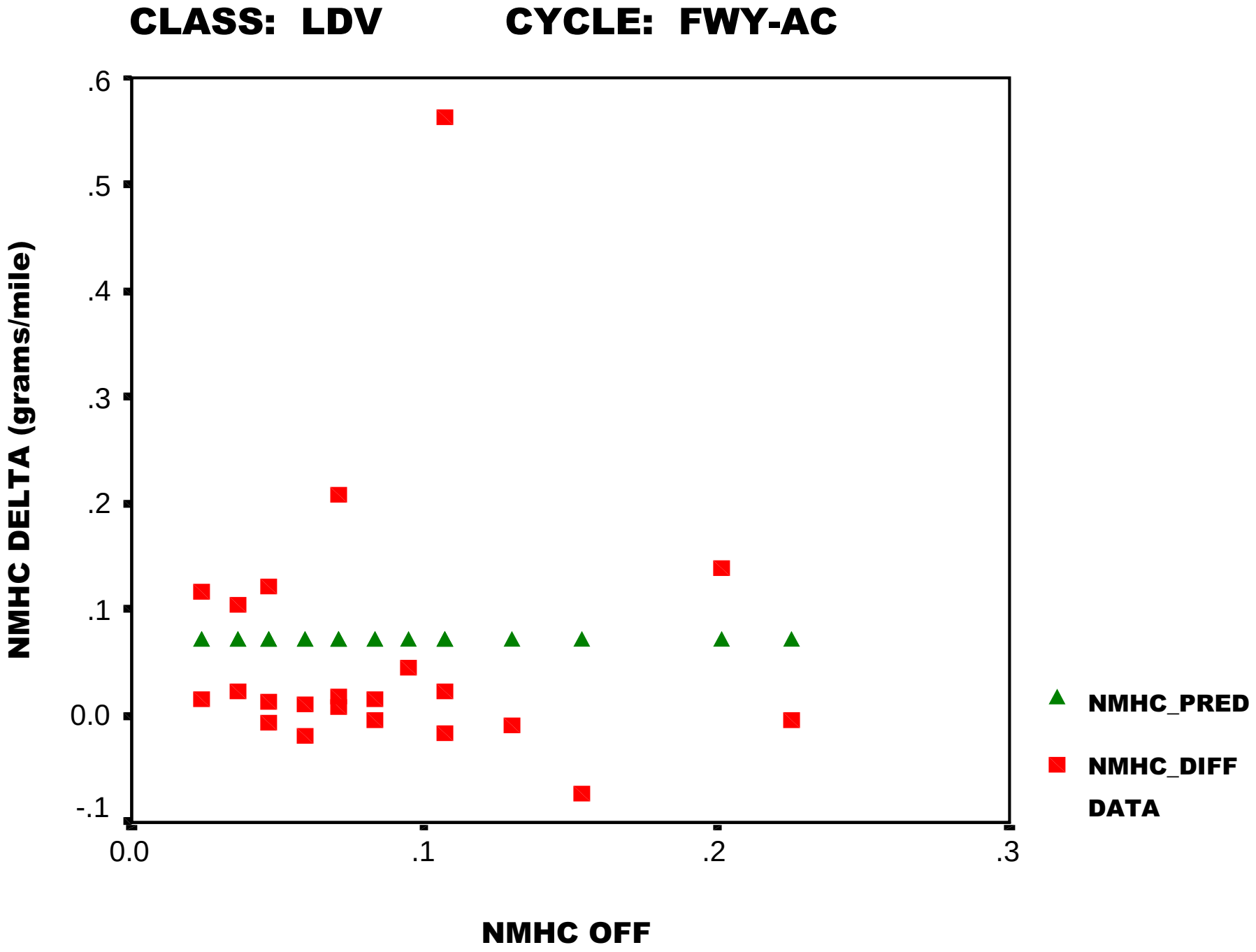

CLASS: LDT
CYCLE: ART-EF
CO DELTA (grams/mile)
20
10
0
-10
-20
-10
0
10
20
30
CO OFF
CO_PRED
CO_DIFF
DATA

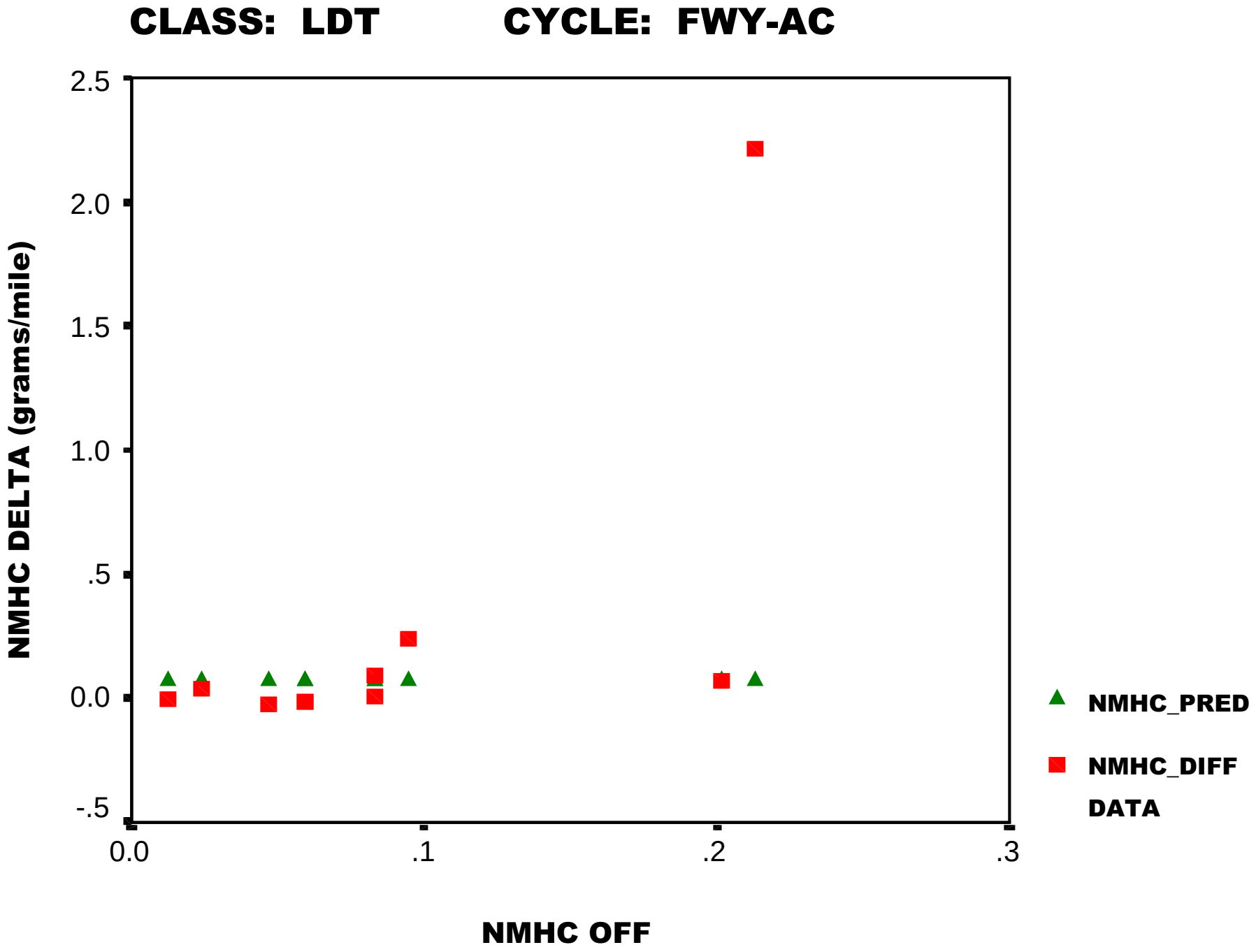

CLASS: LDT
CYCLE: FWY-AC
CO DELTA (grams/mile)
160
140
120
100
80
60
40
20
0
-20
0
10
20
30
CO OFF
CO_PRED
CO_DIFF
DATA

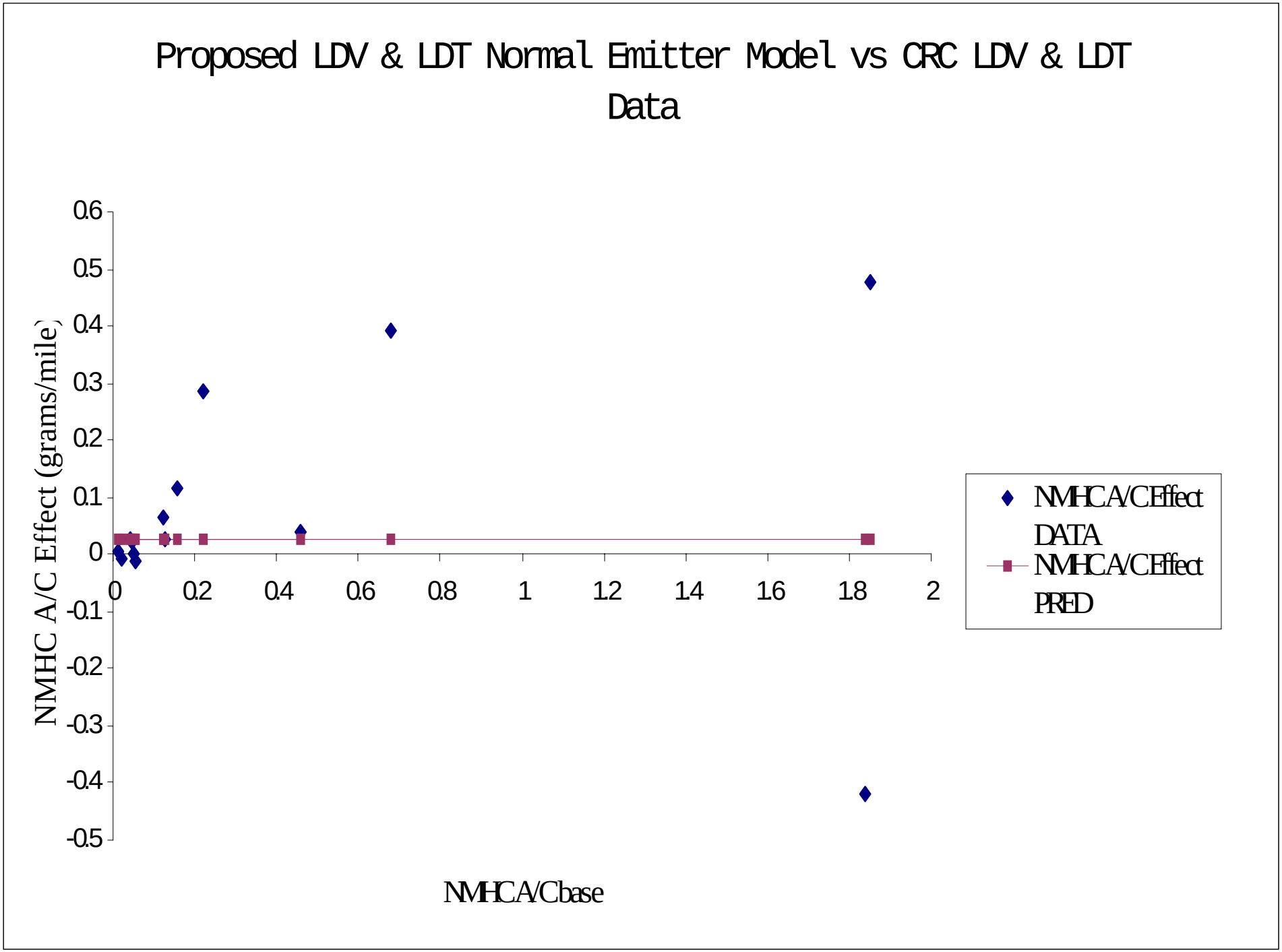

Proposed LDT Normal Emitter Model vs. CRC LDT Data
CO DELTA (grams/mile)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.0
2.0
4.0
6.0
8.0
10.0
12.0
CO OFF
CO A/C Effect DATA
CO A/C Effect PRED


CLASS: LDV
CYCLE: ART-EF
NMHC DELTA (grams/mile)
.3
.2
.1
0.0
-.1
-.2
-.3
-.4
0.0
.1
.2
.3
.4
.5
.6
.7
.8
NMHC OFF
NMHC_PRED
NMHC_DIFF
DATA


CLASS: LDT
CYCLE: ART-EF
NMHC DELTA (grams/mile)
.4
.2
0.0
-.2
-.4
0.0
.1
.2
.3
.4
.5
.6
.7
NMHC OFF
NMHC_PRED
NMHC_DIFF
DATA


CLASS: LDV
CYCLE: FWY-AC
NMHC DELTA (grams/mile)
.6
.5
.4
.3
.2
.1
0.0
-.1
0.0
.1
.2
.3
NMHC OFF
NMHC_PRED
NMHC_DIFF
DATA


CLASS: LDT
CYCLE: FWY-AC
NMHC DELTA (grams/mile)
2.5
2.0
1.5
1.0
.5
0.0
-.5
0.0
.1
.2
.3
NMHC OFF
NMHC_PRED
NMHC_DIFF
DATA


Proposed LDV & LDT Normal Emitter Model vs CRC LDV & LDT Data
NMHC A/C Effect (grams/mile)
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
NMHCA/Cbase
NMHCA/CEffect DATA
NMHCA/CEffect PRED